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Polarised Headlight Filters

By V. J. JEHU, M.Sc., A.Inst.P.

Summary

One way of reducing the glare from headlamps is to use a polarised headlight system. In this paper the relative merits, for this purpose, of commercially available filters are discussed. A second paper will discuss the widely differing proposals that have been put forward in America and in Germany for the use of polarised headlights, and gives the results of tests made with an alternative system.

If an object which is neither very light nor very dark is to appear as bright in polarised light, when seen through the visor, as it normally appears in unpolarised light, about five times as much light is needed. When the transmission and extinction coefficients of the polarising material are known, it is possible to compare the performance of a polarised headlight system with that of systems using ordinary light, in terms of the seeing distances of a standard object. A high intensity polarised beam can only be used if the beam is almost completely polarised. At lower beam intensities less stringent demands are made on the polariser.

The extinction of oncoming polarised lights by the visor depends upon the accuracy of its setting, and may also be influenced by the properties of the windscreen. For a particular polariser the light leakage was increased on the average 150 times for a toughened-glass windscreen and four times for a laminated-glass screen. It is evident that existing types of toughened-glass windscreen could not be used with polarised headlights, unless the visor were mounted outside the windscreen

Introduction

When two vehicles, using conventional headlighting, meet on a road at night both drivers are conscious of the discomfort caused by the glare from the oncoming headlights. More serious than the discomfort, however, is the loss in forward visibility for both drivers. Glare can be limited by careful aiming of suitably shaped beams, but the result must always be a compromise between adequate visibility and discomfort. It has often been suggested that this state of affairs can be overcome if both drivers use a polarised headlight system. In this paper the factors which influence the performance of opposed polarised headlight beams are examined.

(1) The Polarised Headlight System

The suggested method of polarising headlight beams requires filters over the headlamps so aligned that the plane of vibration of the emergent light is at 45 deg. to the horizontal plane (Fig. 1). The driver views the road ahead through a similarly aligned analyser, which may take the form of a visor or spectacles. The vibration axis* of this analyser will be perpendicular to that of light from the headlamps of an approaching vehicle fitted in the same way, so that the analyser discriminates between the driver's own useful light and the unwanted glare light.

The desirable properties of a polarising material are a high transmission coefficient p for a single sheet and a very low extinction coefficient x for two sheets whose vibration axes are exactly crossed (see appendix). In practice it appears that a value of the transmission coefficient as high as 0.5 for ordinary light can only be achieved

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* By the vibration axis of a polariser is meant the direction in the polarising sheet which lies in the plane of vibration of the electric vector of the transmitted light.

with incomplete polarisation, and therefore a relatively high transmission when crossed. Three commercially available polarisers had the following values :—

Polariser 1: $p = 0.37$, $x = 0.0045$
Polariser 2: $p = 0.28$, $x = 0.00005$
Polariser 3: $p = 0.41$, $x = 0.00028$

It is evident that the transmission and extinction coefficients of polarisers can be varied within wide limits. The most suitable values for polarised headlights will depend to a large extent upon the intensity of the beams which it is proposed to use. This will be considered in more detail later.

(2) The Driver's Own Beam

Plane polarisation of headlight beams reduces the light available to the driver. The polarisers over the lamps reduce the light to a fraction p of its initial intensity. There is a further reduction in the light which reaches the driver's eyes due to the analyser. If the light reflected back to the driver is still plane polarised it will be reduced by a further factor $2p$ by the analyser (see appendix). After transmission through the polarisers and analyser, therefore, the residue of the initial light is $2p^2$. If p is 0.37 (polariser 1) the light which reaches the driver's eyes from his own headlamps via the object is 2 x 0.37^2 or 27.4 per cent. of the light which would be available without polarisation. In other words, neglecting any depolarisation of the light on reflection from an object, the headlamps must provide 3.6 times as much light for the object to have the same apparent luminance with the polarised headlight system as in ordinary light.

(3) Depolarisation on Reflection

The road ahead and objects on the road are revealed by the light that is reflected back to the vehicle driver. When polarised light is reflected by objects such as pedestrians' clothing, some depolarisation may occur, the amount appearing to depend to a great extent on the reflection properties of the cloth. Light that penetrates the surface of a black cloth is absorbed; the reflected light is returned from the surface with very little depolarisation. A large part of the light reflected from a white cloth, however, comes from the interior of the material, where it becomes depolarised by numerous reflections.

If r is the polarised fraction of the light reflected from an object, the visor will transmit an amount $2pr$ of this light. It will also transmit an amount $p(1-r)$ of the remainder of the reflected light $(1-r)$, which is *depolarised*. The total light transmitted by the visor is therefore

$$2pr + p(1-r) = p(1+r).$$

The polarisers at the headlamps reduce the light which illuminates the object to a fraction p of its unpolarised intensity. Considering the total light losses at the polarisers and the analyser, therefore, the light available to reveal an object is reduced to a fraction $p^2(1+r)$ of its intensity before polarisation, when account is taken of the depolarisation of the incident light which occurs upon reflection at the object.

Measurements have been made of the polarised fraction of the light reflected from cloths of varying luminance factor ranging from black to white. The angles of illumination and view were approximately normal, as they are in the headlight case. The apparent luminances of the cloth illuminated with polarised light were measured with a visual telephotometer, first through a parallel and then through a crossed visor. The light transmitted by the parallel visor is $p(1+r)$, and that transmitted by the crossed visor is $p(1-r)$, so that the ratio of the difference of these readings to their sum is the polarised fraction of the reflected light. The results are shown in Fig 2; Table 1 gives the effective light fractions after transmission and reflection for the luminance factors 0.02, 0.07 and 0.15. The majority of vertical

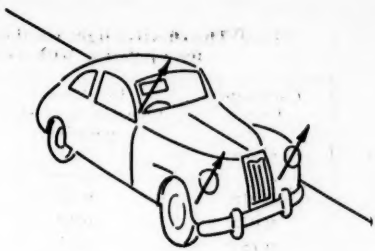

Fig. 1 (right). The polarised headlight system.

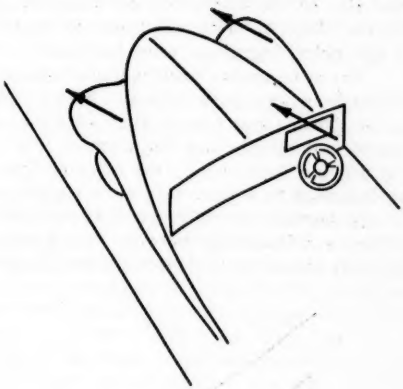

Fig. 2 (below). The relationship between the fraction of polarised light reflected unchanged from cloth and its luminance factor.

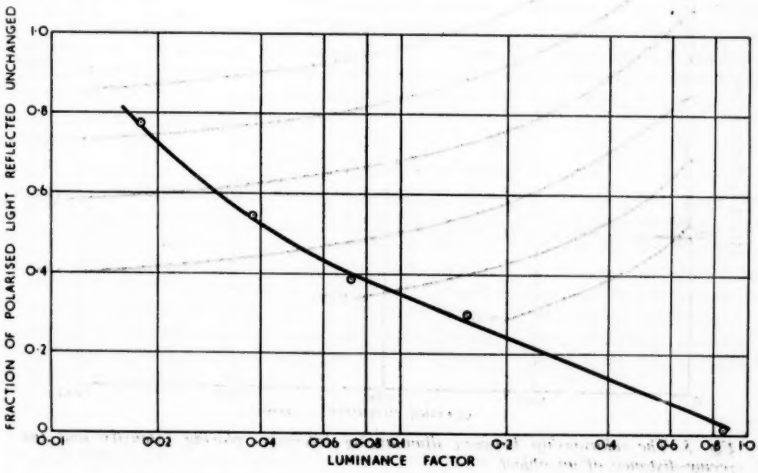

Table 1

The effective light fractions after transmission and reflection for a polariser with a transmission coefficient $p_s^2 = 0.37$

Luminance Factor of cloth	Fraction of reflected light still polarised r	Transmission of analyser $p\,(1 + r)$	Transmission of polariser and analyser $p^2(1 + r)$
0.018	0.76	0.65	0.24
0.073	0.40	0.518	0.192
0.155	0.28	0.474	0.175

objects which make up the night-time scene have luminance factors within this range. The last column of Table 1 shows that, allowing for losses in polariser and analyser and also for depolarisation on reflection, approximately five times the light is needed for the object to appear as bright in the polarised headlight system as it would appear if the polarising filters were removed.

The road surface itself is illuminated and viewed obliquely, and may depolarise the return beam in a different way. Visual inspection suggests that the light reflected back to the driver from various kinds of road surface is very largely depolarised. Assuming complete depolarisation, the contrast, that is the ratio of the luminances of an object for which a fraction r of the reflected light is still polarised and the road surface, will be increased by a factor $(1 + r)$ compared with the contrast obtained in ordinary light.

In previous work[1] an object with a luminance factor of 0.07 has been used to obtain a relationship between the glaring intensity of an opposing headlight, the intensity aimed by an observer's own lamp at the object, and the distance at which the

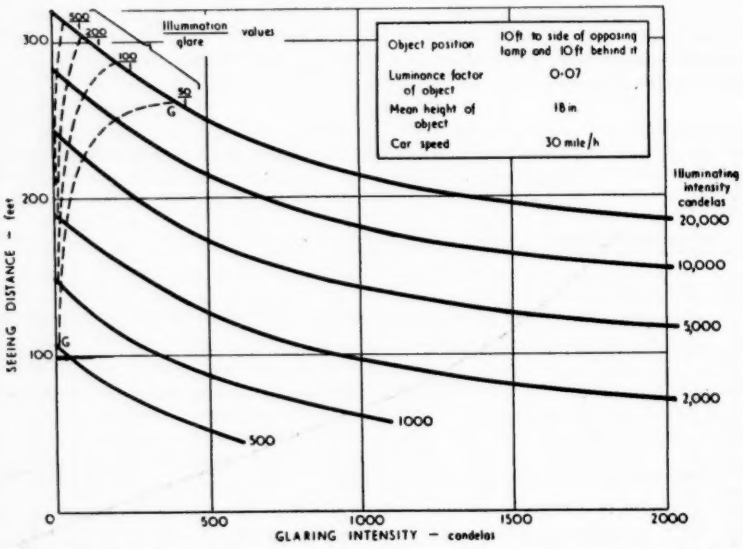

Fig. 3. The relationship between illuminating intensity, glaring intensity and the seeing-distance of an object.

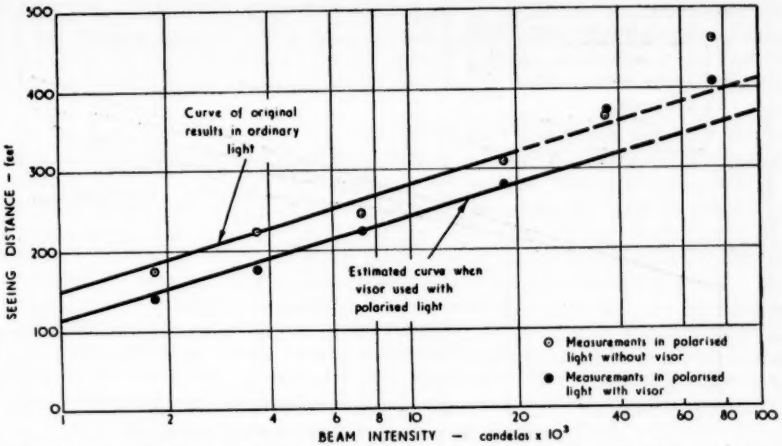

Fig. 4. A comparison of estimated and measured losses in open road seeing-distances when a visor is used with polarised light. (In the case of polarised light the beam intensity is measured after polarisation).

object could be identified. The relationship found for ordinary light for the test situation is shown in Fig. 3. The upper curve in Fig. 4 shows the seeing-distance/beam intensity curve for the object with a luminance factor of 0.07 in the absence of glare, as already given in Fig. 3. This curve will also apply to a beam of polarised light if no visor is used. Table 1 shows that when such an object is illuminated by polarised light and is viewed through the visor the effective beam intensity (measured after polarisation) is reduced to about one-half.

Neglecting any change in contrast between the object and the road surface, the lower curve in Fig. 4 shows the relationship which should apply if the visor is used, the incident beam intensities required to see the object at specific distances being increased in the ratio 1 : 0.518. The points shown on the figure are actual measured seeing distances of the object in polarised light with and without the visor, for a polariser with a transmission coefficient of 0.37. The agreement between calculation and experiment suggests that the change in contrast between the object and its background introduced by the polarised headlight system can be ignored when estimating the performance of the system.

(4) The Opposing Beam

So far, consideration has been given only to the case of the open road. When another vehicle is encountered, glare from the oncoming headlights reduces forward visibility. Figure 3 shows how much seeing is affected by glare for the standard test situation. When the oncoming headlights are polarised in a plane perpendicular to that of the observer's visor, glare is reduced to a small fraction of its normal intensity. With exactly crossed polarisers the amount by which it is reduced depends on the completeness of the plane polarisation of light achieved in the polarising material.

The ratio of the reducing fraction for the driver's useful light to the reduction factor for glare light is:—

$$\frac{p^2(1+r)}{x}$$

If the headlights are such that the intensity directed at the test object equals that

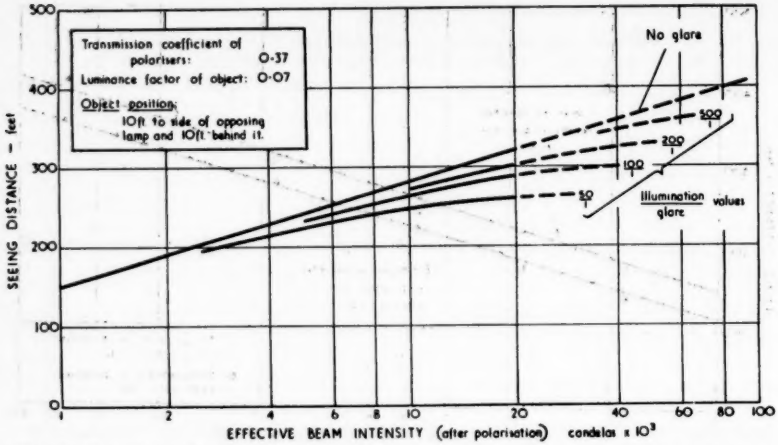

Fig. 5. The relationship between seeing-distance and effective beam intensity for polarisers having a range of illumination/glare ratios.

directed at the opposing driver's eyes, this is also the ratio of effective illuminating intensity to effective glaring intensity. Knowing the value of this ratio, the maximum reduction in seeing distance which could be produced by the opposing polarised beam can be estimated. For an arbitrary illumination/glare ratio of 50 : 1 the seeing-distance/beam intensity curve for the standard test situation will be defined by the intersection of the curve GG with the family of curves shown in Fig. 3. The curves relating to other arbitrary values of the illumination/glare ratio are also plotted in Fig. 3.

The relationship between seeing distance and effective beam intensity of the polarised headlight system is given in Fig. 5 for the case of no glare. The effect on seeing of the maximum glare from a similar opposing beam, for several different polarisers giving a range of values of the illumination/glare ratio, is shown by the appropriately labelled curves. They define the limits within which polarised headlight systems may be expected to operate under the standard test conditions. In order to reach the higher intensities the beams will necessarily be aimed with their maxima straight ahead and undipped, so that both drivers will experience almost the maximum glare. It is clear from Fig. 5 that the value of the illumination/glare ratio becomes increasingly important as the beam intensity of the system is increased, the departure from the no glare condition being more rapid for a low value of the ratio than for a high one. For a value of the ratio as low as 50 : 1 and opposing effective beam intensities of 20,000 cd a stage is reached where little improvement in seeing may be expected for a further increase in beam intensity.

(5) The Most Suitable Polariser

Having examined the way in which the polariser, analyser and the opposing glare affect seeing, the performances of specific polarisers can be estimated in terms of the intensity available at the lamps before polarisation. For an object with a luminance factor of 0.07, the illumination/glare ratio for polariser 1 ($p=0.37$, $x=0.0045$) is 40:1, and for polariser 2 ($p=0.28$, $x=0.00005$) is 2200:1. The expected performances with these two polarisers are shown in Fig. 6, in which OO is the relationship between beam intensity and seeing for the standard test object on the open road. This is reduced to

P_1P_1, when polariser 1 is placed over the lamps, which in turn is reduced to V_1V_1 when the visor is used. Finally, the maximum glare from similar opposing lamps reduces seeing to G_1G_1. When meeting another vehicle, therefore, seeing will be between V_1V_1 and G_1G_1, and on the open road seeing will be defined by P_1P_1 if the visor is not used.

In the same way V_2V_2 and P_2P_2 represent seeing conditions with and without the visor for polariser 2; because, however, glare is in this instance reduced to negligible proportions, V_2V_2 also represents conditions when another vehicle is encountered.

Figure 6 shows that for beam intensities less than about 40,000 cd before polarisation (the intersection of G_1G_1 and G_2G_2), polariser 1 will give a better performance than polariser 2. At high intensities, however, the reverse is true, the more complete elimination of glare by polariser 2 more than offsetting its poorer transmission p.

Figure 7 shows the corresponding curves for polariser 3 ($p=0.41$, $x=0.00028$), for which the illumination/glare ratio is about 850:1 for an object with a luminance factor of 0.07. This polariser gives a better performance than either polariser 1 or 2 at all likely beam intensities, and appears to be a good compromise between the requirements for a high value of p on the one hand, and a low value of x on the other.

(6) Accuracy of Polariser Settings

In the foregoing discussion on the relative merits of polarisers with different values of p and x, it has been assumed that the analyser is exactly crossed with the polarisers on the opposing headlamps. In practice this might not be so, either through incorrect adjustment or because of the camber of the road. The light transmitted by two similar polarisers with their planes of polarisation at an angle θ has been shown (see appendix) to be

$$2(y^2+z^2)\cos^2\theta+4\sqrt{y}\sqrt{z}(y+z)\sin\theta\cos\theta+4\,yz\sin^2\theta.$$

For angles which are close to 90 deg., the first two terms of this expression determine the magnitude of the light transmitted because of the incorrect adjustment; the third term is approximately equal to the extinction coefficient. The relative contributions

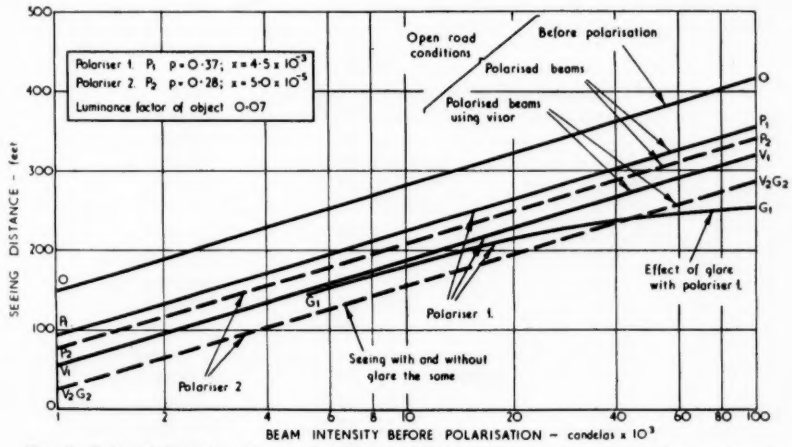

Fig. 6. Estimated seeing-distances for two polarisers, taking into account losses due to polariser, analyser and to the maximum opposing glare.

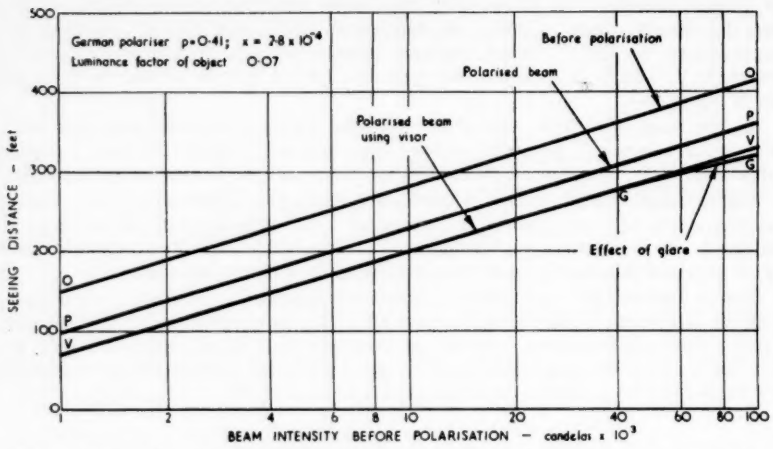

Fig. 7. Estimated seeing-distances for a German polariser, taking into account losses due to polariser, analyser and to the maximum opposing glare.

Table 2

The relative magnitudes of the light leakage through crossed polarisers due to the inaccuracy of setting and the extinction coefficient

Polariser	Relative light leakage due to :—		
	Extinction coefficient x	θ	Inaccuracy of setting $2(y^2+z^2)\cos^2\theta + 4\sqrt{y}\sqrt{z}\sin\theta\cos\theta\,(y+z)$
1	0.0045	89	0.00094
		88	0.00203
		87	0.00329
		86	0.00473
		85	0.00630
2	0.00005	89	0.000117
		88	0.000328
		87	0.000633
		86	0.001048
		85	0.001540
3	0.00028	89	0.00034
		88	0.00088
		87	0.00163
		86	0.00261
		85	0.00376

of these two items to the total light leakage have been evaluated in Table 2 for small angles for the three polarisers already considered.

For polariser 1 the light leakage which may occur with incorrect adjustment is as large as that due to the extinction coefficient when the error of adjustment is 4 deg. For polarisers 2 and 3, however, the light leakage for an error of adjustment of only 1 deg. is greater than that due to the extinction coefficient. Thus the highest order of accuracy of adjustment will be required for the system which relies for its performance on a very low value of the extinction coefficient of its polariser.

Spectacles have an advantage over visors mounted in the vehicle because incorrect adjustments between the polariser and analyser can easily be eliminated by small movements of the head, if one vehicle only is encountered. If the spectacles are such that only part of the field of view is polarised, movement of the head will also bring the analyser into operation or dispense with it as required. They might not be popular, however, with people who are not accustomed to wearing spectacles. In practice, the windscreen will usually be interposed between the polariser over the opposing lamps and the analyser, and may itself add to the leakage of light through the crossed polarisers. The effect of this will be to increase the effective value of the extinction coefficient relative to that of the error in setting, so that the performance of the system as a whole will be less efficient and will become less dependent on the accuracy of setting, although of course the performance when the polarisers are accurately crossed will be worsened.

(7) The Windscreen

Toughened glass, which is almost universal on British cars, radically disturbs the polarisation of the incident light, and introduces a considerable leakage of light in which the strain pattern of the glass is clearly visible. Although usually having a much less noticeable effect, laminated glass may also introduce some leakage of light.

Measurements have been made of the effect on the transmission of crossed polarisers, when a laminated windscreen was introduced between them. The results, given in Table 3, show that the leakage of light varied considerably from one part of the windscreen to another. For polariser 2 the transmission was increased between 1.5 and 30 times, and for polariser 3, between 1.2 and 15 times. The mean increases were 8.1 times for polariser 2 and 4.3 times for polariser 3, corresponding to reductions

Table 3

The increase in light transmitted through crossed polarisers caused by a laminated-glass windscreen

Part of windscreen	Increase in light through crossed polarisers 2	Increase in light through crossed polarisers 3
bottom right 1	× 4.0	× 2.6
bottom right 2	1.5	1.2
bottom left 1	6.8	3.5
bottom left 2	1.6	1.6
top left 1	5.9	4.0
top left 2	31.1	14.5
top right 1	2.9	1.7
top right 2	11.0	5.5
mean light increases	8.1	4.3

Table 4

The increase in light transmitted through crossed polarisers caused by a toughened-glass windscreen

Part of windscreen	Increase in light through crossed polarisers 2	Increase in light through crossed polarisers 3
bottom right 1	×388	×168
bottom right 2	46	25
bottom left 1	580	280
bottom left 2	118	67
top left 1	508	254
top left 2	84	53
top right 1	489	246
top right 2	125	80
mean light increases	292	147

in the illumination/glare ratio from 2,200:1 to 270:1 and from 850:1 to 200:1 respectively. Thus, the more complete the incident polarisation, the greater is the effect of a windscreen on the leakage of light through the crossed polarisers.

Similar measurements were made with a toughened windscreen, and the results are given in Table 4. In this case the mean increases in the light transmitted through crossed polarisers were 292 times for polariser 2 and 147 times for polariser 3, corresponding to reductions in the illumination/glare ratios to the very low values of 7.5:1 and 5.8:1 respectively.

It is clear from these results that the use of polarised light would necessitate a laminated windscreen unless optically inactive toughened glass could be produced.

(8) Conclusion

Data obtained in ordinary light relating the intensity of the headlight beam illuminating a test object, and the distance away at which the object can be seen in the presence of glare, can be applied to polarised headlight beams when the transmission and extinction coefficients of the polarising filter, and the fraction of the polarised light which is unchanged after reflection at the object, are known. In this way direct comparison is possible between seeing distances obtained with ordinary and polarised headlight systems.

Appendix

Ordinary unpolarised light may be regarded as a transverse vibration in which the plane of vibration changes so rapidly that even in a very short interval of time all directions are equally represented. By resolving these vibrations along two mutually perpendicular directions the light can be divided into two equal beams, in each of which the vibration is all in one plane and perpendicular to the vibration in the other beam. For our purpose, we may regard unpolarised light as consisting of these two plane components. A polarising filter placed in the path of the unpolarised light transmits a fraction p, which we may regard as made up of y vibrating in the direction parallel to the vibration axis of the filter, and z in a perpendicular direction. The fraction p of unpolarised light transmitted by the polariser is called its transmission coefficient, and clearly

$$p = y + z.$$

Considering the two components of the incident light separately, that which is

parallel to the vibration axis of the polariser has an initial intensity of $\frac{1}{2}$, and a transmitted intensity of y. The transmission factor of the polariser for light parallel to its vibration axis is therefore $2y$. Similarly, the transmission factor for light perpendicular to the vibration axis is $2z$. The value of z will be extremely small compared with that of y for a good polariser.

Consider now the passage of the polarised light through a second polarising sheet called the analyser, exactly similar to the first, and with its vibration axis at an angle θ to that of the polariser. Resolving the amplitudes of the components (proportional to the square roots of the intensities) parallel and perpendicular to the vibration axis of the polariser, along and perpendicular to the vibration axis of the analyser, the amplitude of the parallel component is

$$\sqrt{y}\cos\theta + \sqrt{z}\sin\theta,$$

and that of the perpendicular component is

$$\sqrt{y}\sin\theta + \sqrt{z}\cos\theta,$$

The respective intensities of the two components are

$$y\cos^2\theta + z\sin^2\theta + 2\sqrt{y}\sqrt{z}\sin\theta\cos\theta,$$

and

$$y\sin^2\theta + z\cos^2\theta + 2\sqrt{y}\sqrt{z}\sin\theta\cos\theta.$$

After transmission through the analyser the intensity of the parallel component is

$$2y\,(y\cos^2\theta + z\sin^2\theta + 2\sqrt{y}\sqrt{z}\sin\theta\cos\theta)$$

and that of the perpendicular component is

$$2z\,(y\sin^2\theta + z\cos^2\theta + 2\sqrt{y}\sqrt{z}\sin\theta\cos\theta).$$

The total intensity of the emergent light is therefore

$$2\,(y^2 + z^2)\cos^2\theta + 4\,(y + z)\sqrt{y}\sqrt{z}\sin\theta\cos\theta + 4yz\sin^2\theta;$$

denoting the light transmitted when polariser and analyser are exactly crossed $(\theta = \frac{\pi}{2})$ by x, we have

$$x = 4yz.$$

This fraction is called the extinction coefficient of the polarising material.

Acknowledgment

The work described in this paper was carried out as part of the programme of the Road Research Board of the Department of Scientific and Industrial Research. The paper is published by permission of the Director of Road Research.

Reference

(1) Jehu, V. J. Trans. Illum. Eng. Soc. (London), **20**, 57 (1955).

Some Polarised Headlight Systems

By V. J. JEHU, M.Sc., A.Inst.P.

Summary

This is the second of two papers dealing with polarised headlight systems. The first paper discussed the relative merits of commercially available filters for polarising headlights. The present paper discusses the widely differing proposals that have been put forward in America and Germany for the use of polarised headlights, and records the results of tests made with an alternative system. The discussion and tests are concerned only with the benefits to drivers of vehicles. The consequences to pedal cyclists and pedestrians are not discussed in this paper.

Any polarising device fitted to a headlamp will reduce the light available for seeing. The American system overcomes this handicap by increasing the power of the polarised headlights, so that the user always sees at least as well as with the driving beam of conventional headlights; the German system on the other hand uses a polarised beam which is no more glaring to face without a visor than existing German meeting beams. Neither system would be easy to introduce, because initially the benefits to the user would, for different reasons, be iimited to the occasional meeting with another user.

Polarisation of existing driving beams might provide a system which operated between these two extremes, and might enable the user to see objects in his own beam at greater distances than usual even when meeting normal beams. Driver-appreciation tests with the system, however, suggest that it does not illuminate the road near the vehicle well enough to inspire confidence, and that the loss in silhouette seeing is a real disadvantage. Preliminary experiments suggest that both criticisms might be overcome with an in-part polarised system in which the near view is illuminated by unpolarised light and the distant view by polarised light.

Introduction

In a previous paper(1) the light losses introduced by adopting a system of polarised headlighting were evaluated, and some account was taken of the reduction in the effectiveness of the system by the windscreen material, and by errors in crossing the analyser with the polarisers covering oncoming headlights. In the present paper, proposals which have been put forward in America and Germany for the use of polarised headlights are examined in the light of the information given in the previous paper, and alternative proposals are discussed. Driver-appreciation tests carried out with one of these alternative systems are described.

(1) The American System

The proposed American system(2) uses a beam with a polarised-light intensity of 100,000 cd, the intention being at least to equal the open-road seeing-distance provided by the upper beams of normal headlights, when all the light losses have been accounted for. The transmission coefficient p of the American polarising material is 0.37. The system entails the use of headlamps with 125-watt filaments, and a larger generator and heavier wiring to supply the necessary power.

In Fig. 1 is shown the relationship obtained between the effective beam intensity of a polarised headlight system, that is to say the intensity available to reveal a standard object after allowing for the losses in light at the polarisers and the analyser, and its distance away. Taking into account the light loss at the viewer, the effective beam intensity of the American polarised beam becomes 50,000 cd approximately,

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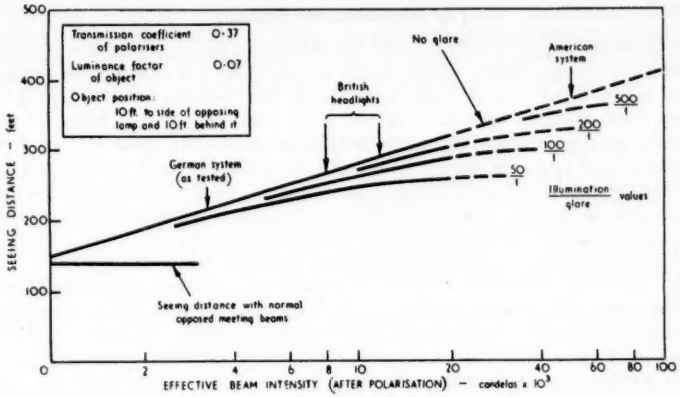


Fig. 1. The relationship between seeing-distance and effective beam intensity for polarisers having a range of illumination/glare ratios.

according to Table 1 of the previous paper. Extrapolation of the measurements of seeing-distance with and without glare beyond 20,000 cd suggests that the open-road seeing-distance through the visor with a beam of 50,000 cd is 375 ft. (Fig. 1), which will be reduced during an encounter according to the illumination/glare ratio characteristic of the combination of windscreen and viewer used. This should be at least of the order of 200:1 if an appreciable loss in performance is to be avoided.

During the period that the system was on the road at the same time as normal headlights, it was intended that the driver with the powerful polarised beam should depress to a non-polarised beam when meeting normal headlights. The number of encounters with vehicles equipped with polarised light would be small in the early stages of the transition period, so that there would be little immediate benefit from the considerable outlay incurred by the installation. Inevitably such a system could only be introduced gradually as standard equipment on new vehicles.

Table 1

Polarised beam (A) versus normal meeting beam (B)

Road surface	Polarised lamp settings	Straight ahead		1 deg. down		2 deg. down	
	Beam	A	B	A	B	A	B
Dry	Preference without glare	5	3	8	0	6½	1½
	Preference with glare	6	2	8	0	6½	1½
	Polarised beam preferred	5		1		2	
Wet	Preference without glare	7	1	7	1		
	Preference with glare	7	1	7	1		
	Polarised beam preferred	4		4			

(2) The German System

The German system[3] differs from the American in polarising the meeting beam rather than the driving beam, which is still provided by the existing headlights. Two additional lamps fitted with 50-watt bulbs supply this meeting beam which is intended to comply with existing regulations in Germany regarding glare. Since these specify a maximum glaring intensity near the horizontal plane of about 600 cd from each lamp, the forward reach of such a beam will obviously be very restricted, the seeing-distance for the standard object being of the order of 160 ft. without the visor. Opposed meeting beams of modern block-lens British headlamps when correctly aimed give a seeing-distance for the standard object in its test position of about 140 ft., and a similar figure would be expected for opposed German Bilux lamps.

Apart from the reduction in glare in occasional meetings with similar polarised beams, the major immediate benefit of the German polarised beam would lie in its better road illumination, consequent upon using the whole of both lamp reflectors instead of only the upper halves as with the present German lamps.

Thus neither the American nor the German driver who fitted the respective polarised systems would derive much immediate benefit from the change over. Neither would see very differently when meeting normal dipped beams, and both would still be required to switch from upper to lower beams for the majority of encounters.

(3) Alternative Systems

From the foregoing discussion it will be seen that one of the major obstacles facing the introduction of a polarised headlight system is the transitional period, during which the system would not be used to its best advantage. Both systems so far proposed possess the inherent weakness that they offer little inducement to the individual driver to fit them voluntarily. It would be easier to introduce a system if the benefits to the driver who invested in it were immediate and obvious, particularly if the equipment were not costly. Such a system would operate somewhere between the American and German systems. Two alternative ways of attempting to do this are outlined below.

In the first method, special polarised lamps can be fitted in the German manner and the normal headlights retained for open-road work, the polarised lamps being aimed in a predetermined way such that the forward beam intensity is considerably in excess of that of normal meeting beams.

According to illumination values recorded at test objects during comparative trials between the German polarised beam and the normal Bilux beam[3], it appears that, as tested, the intensity of the polarised beam just below the horizontal plane was 6,500 cd, which would not of course comply with existing German regulations. The effective beam intensity for the object with a luminance factor of 0.07 would be 3,250 cd giving an open-road seeing-distance of about 215 ft. At this comparatively low intensity the performance of the system depends less on the illumination/glare ratio of the windscreen-visor combination than it does at higher intensities, so that during an encounter with a similar polarised beam the seeing-distance would probably not drop much below about 200 ft., a marked improvement on the 140 ft. obtained with correctly aimed normal beams. Aimed in this way, the polarised lamps would also show some improvement in seeing when meeting normal lamps. Tilting the lamps upwards still further would effect an even greater improvement, until with the lamps aimed straight ahead, an effective beam intensity of 13,000 cd would be obtained with a maximum possible open-road seeing-distance of about 300 ft., which might drop to about 250 ft. during an encounter.

The second method is to polarise the open-road beam of existing headlights. Modern British headlamps give a driving beam with an intensity in the range

40,000-60,000 cd. Polarising these lights and using a visor would mean that for an object with a luminance factor of 0.07, the effective beam intensity would become 8,000-12,000 cd with a mean value of 10,000 cd, giving an open-road seeing-distance of 285 ft., comparable with that of the undipped German polarised lamps.

(4) Polarisation of Existing Headlights

The polarisation of existing open-road beams appears to be a possible practical compromise between the extremes of the American and German proposals. On the one hand it does not require new and heavier electrical equipment, and on the other hand the polarised beam would be sufficiently powerful to give the driver behind the lamps a noticeable improvement in the identification of objects on the road when meeting normal unpolarised beams.

During encounters with polarised lights, seeing of objects along the nearside would be improved for both drivers by a factor of approximately 2:1 compared with normal meeting beams. This improvement would be achieved at the expense of seeing on the open road, which would drop to 0.75 of its former value if the visor were used all the time, and to 0.85 if the visor were not used on the open road. Provided that the driver would accept this loss in seeing on the open road, the system would virtually become a single beam system, which has always been the ideal of the headlamp designer.

The advantages mentioned above prompted a practical investigation of the possibilities of the system, in which drivers were asked to compare the polarised system, with the headlamps set in various ways, with normal unpolarised meeting beams.

(5) Differences between the Systems

The characteristics of the polarised and the normal meeting beams are very different. Some theoretical seeing-distances evaluated in the appendix show that objects on the road are revealed much further away with the opposed polarised beams than with normal beams. Headlight beams, however, are judged not only on their ability to reveal objects, but also on the way they reveal the road surface and its verges.

When illuminated by the normal meeting beam the road surface appears very bright close to the vehicle, but the brightness rapidly diminishes as the distance from the vehicle increases. In the light of the undipped polarised beam the same road surface appears much more uniformly bright, the distant road being brighter than when seen in the normal beam, but the road close to the vehicle being very much dimmer. The general impression immediately after experiencing the normal meeting beam is of a lack of light around the vehicle. Dipping the polarised beam brightens the foreground at the expense of the distant view. It was for this reason that driver-appreciation tests were carried out, in which observers were asked for their opinions of different settings of the polarised beam.

The polarised and normal beams also differ as regards the help received from the opposing lamps. The bright patch on the road provided by modern correctly aimed beams reveals objects on the road as silhouettes. With polarised beams the brightness of this patch of light is greatly diminished by the analyser, with the result that silhouette seeing is much less effective. With these important differences between the two lighting systems in mind the driver-appreciation tests can now be considered.

(6) Driver-Appreciation Tests

Tests in which the opinions of drivers are invited have been used from time to time at the Laboratory to compare different types of meeting beam(4). The test site used for these comparisons is a concrete road almost half a mile in length, with a

curve at each end and a long straight section in the centre. Man-sized obstacles with a luminance factor of 0.08 are placed at the sides of the track, and small objects 18 in. high by 12 in. wide are placed along the centre; one side of these obstacles has a luminance factor of 0.08 and the reverse side a factor of 0.02. The lamps to be examined are fitted to two vehicles, which are driven over the course in opposite directions to meet near its centre. The comparisons are made by recording the opinions of drivers after they have repeatedly negotiated the course with the specified beams.

In this instance the two vehicles were each fitted with four modern British block-lens light units, two of which were completely covered with polarisers. The driving beams of the polarised lamps and the meeting beams of the unpolarised lamps were used, the former being set straight ahead, then 1 deg. down, and finally 2 deg. down, whilst the latter were aimed in the normal way throughout. Each observer was provided with a questionnaire which was completed stage by stage as the tests proceeded. At each setting of the polarised lamps an observer made four runs as driver and four runs as passenger before forming an opinion. Some preliminary runs were made to accustom the observers to the polarised beams, and to allow them to choose between spectacle analysers or visors mounted in the vehicles.

(6.1) Results

The preferences expressed by the observers are given in Table 1, in which half-votes arise from observers having no preference.

Considering first the comparisons of the individual settings of the polarised lamps with the normal meeting beams, there was always a majority who favoured the polarised beam; on a dry road this majority became absolute at the setting of 1 deg. down. This result suggests that a lamp setting which compromised to some extent between distant illumination on the one hand and a bright road surface on the other would generally be preferred.

In addition to the individual comparisons with the normal meeting beam, the observers were also asked to state a preference for one or other of the three settings of the polarised beams. On a dry road it was somewhat surprising, in view of the result quoted above, to find that five observers preferred the beams to be aimed straight ahead for distant seeing, two preferred the setting of 2 deg. down, which gave the brightest road surface, and only one observer preferred the compromise setting of 1 deg. down. When the road was wet, opinions were equally divided between the polarised beam aimed straight ahead and the beam dipped 1 deg. down. Most of the observers commented upon the comparatively dark appearance of the view ahead with the polarised beams, and some also noted the loss in effectiveness of silhouette seeing, particularly of objects in the centre of the road.

These results and comments suggest that polarisation of existing driving beams would not be popular, in spite of the increased seeing-distances of nearside objects they would provide in meetings with similar beams. The road surface near the vehicle must also be well illuminated to allow easy positioning of the vehicle on the road. The ability to do this inspires confidence in a driver.

The tests just described directed attention to the possibilities of an in-part polarised beam, that is to say, a beam in which the distant view was illuminated by polarised light, and the near view by unpolarised light. Such a scheme might overcome the two main criticisms levelled at the polarised driving beam, viz., the lack of light near the vehicle and the loss in silhouette seeing.

More information about the polarised driving beam was obtained from runs on a test course consisting of a series of bends, a steep hill, and a straight road section. Five cars were equipped with polarised driving beams and with normal meeting beams, three of the polarised beams being British driving beams and the other two German beams aimed with their maximum intensities straight ahead. The test runs were arranged

so that one car met the other four, to gain experience of the polarised beams both under open-road conditions and when meeting a stream of traffic. Some exploratory work was also carried out on a part polarised beam, by fitting auxiliary lamps to the cars with polarised British driving beams to provide a wide fan of unpolarised light directly ahead of the vehicles.

The ten observers who took part in the tests all preferred to drive with the augmented polarised beam. Opinions were equally divided regarding the glare effect of this composite beam, five observers considering it to be appreciably more glaring than the completely polarised beam, and five judging it not to be so. The test did not reveal differences in silhouette seeing because there were no obstacles on the road.

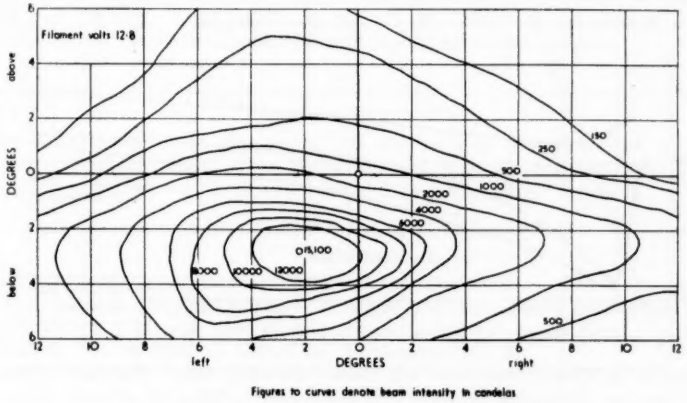
(7) Conclusion

The ultimate aim of this study of polarised headlights is to decide whether a system can be devised which would be easy to introduce. Such a system should not be costly, it should preferably show an immediate benefit to the driver who fits it even when meeting unpolarised beams, and it should be acceptable to pedestrians, cyclists and other road users. The tests reported in this paper, which have been concerned with the driver aspect only, have not revealed any completely satisfactory arrangement, but they indicate that a promising line of investigation to pursue further is an in-part polarised beam.

Appendix

Calculated Seeing-Distances

A method of evaluating seeing with opposed meeting beams in ordinary light has been fully described elsewhere([5]), and will only be outlined here. Basic experimental data relating the seeing-distance of a test object with the illuminating intensity of an observer's own lamp and the glaring intensity of an opposing lamp have been obtained, for a given road width and position of the object (see Fig. 3 of Reference([1])). It has been extended to other widths and object positions by applying the Stiles-Holladay law, which states that the effect on seeing of a glaring light varies inversely as the square of the angular separation between the glare source and the line of sight. The same method can be applied to encounters involving polarised beams when the characteristics of the polariser and windscreen are known. In what follows it has been



Figures to curves denote beam intensity in candelas

Fig. 2. Normal meeting beam from one British lamp.

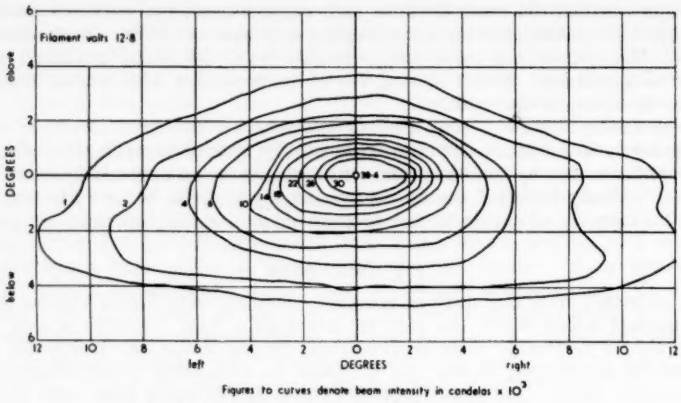


Fig. 3. Open-road beam from one British lamp.

assumed that the polariser has the same characteristics as the German one, viz., transmission coefficient, $p,=0.41$ and extinction coefficient, $x,=0.00028$, since this was, in fact, the polariser used in the appreciation tests, and that the laminated windscreens used increased the leakage of light at the extinction setting by four times.

The normal meeting beam distribution is shown in Fig. 2, and that of the open-road beam before polarisation in Fig. 3. Seeing-distances have been evaluated for three object positions across a road 20 ft. wide, a nearside object 2 ft. from the verge, an object in the centre of the road, and an offside object also 2 ft. from the verge.

Fig. 4 shows how seeing varies for both drivers when normal correctly aimed meeting beams are used. When the vehicles are about 1,200 ft. apart the nearside object is seen 200 ft. away; as the vehicles approach one another the seeing-distance drops to a minimum of 163 ft. By increasing the intensities near the horizontal and sharpening the cut-off towards the offside of the beam as in the new American meeting

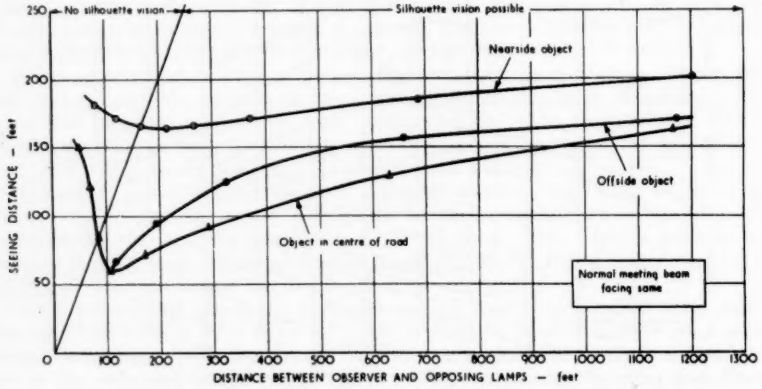

No silhouette vision
Silhouette vision possible
Nearside object
Offside object
Object in centre of road
Normal meeting beam facing same
SEEING DISTANCE – feet
DISTANCE BETWEEN OBSERVER AND OPPOSING LAMPS – feet

Fig. 4. Seeing-distances with normal opposed meeting beams.

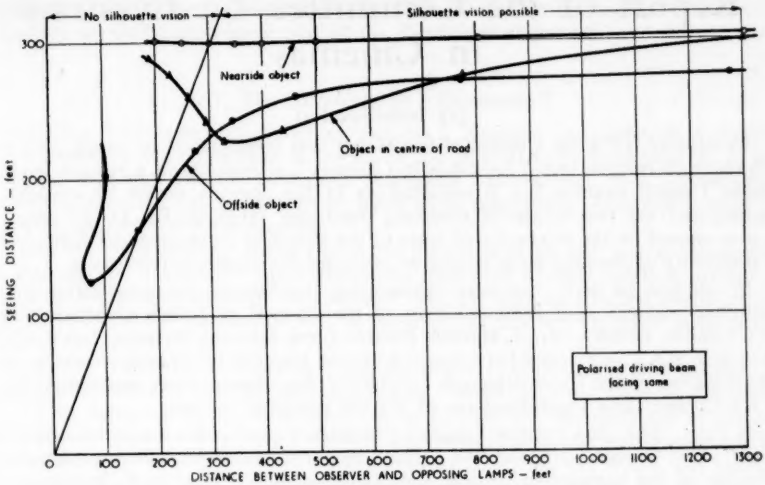


Fig. 5. Seeing-distances with opposed polarised driving beams.

beam, the minimum seeing-distance can be increased to about 200 ft., but it is probable that this represents almost the best that can be achieved with opposed beams in ordinary light. Objects on the offside and in the centre of the road are more difficult to see in the driver's own beam than the nearside object, the minimum seeing-distance for the object in the centre of the road being 60 ft. In practice an object in this position may be seen much further away as a silhouette.

With opposed polarised beams the nearside object can be seen at 300 ft. (Fig. 5), and the minimum seeing-distance for the object in the centre of the road becomes 225 ft., increases of 1.8 times and 3.8 times respectively, compared with normal meeting beams. The longer seeing-distances and the large reduction in glare provide vastly improved seeing conditions for both drivers so far as the identification of objects on the road is concerned. This conclusion neglects any effects due to loss of silhouette seeing, which are more conveniently studied by experimental means.

Acknowledgment

The work described in this paper was carried out as part of the programme of the Road Research Board of the Department of Scientific and Industrial Research. The paper is published by permission of the Director of Road Research.

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Report of the Committee on Eyestrain in Cinemas

(1) Introduction

In October, 1919, the Council of the Society was instrumental in setting up a Joint Committee to enquire into "Eyestrain in Cinemas" in response to a request from the London County Council for information as to the possible causes of eyestrain in cinemas, and the best means of removing them and, in particular, as to "strain on the eyes caused by the proximity of seats to the screen at cinematograph halls, and of the possibility of devising some means of lessening the ill-effects referred to."

In addition to seven members representing the Society, the constitution of this Committee included four representatives of the Council of British Ophthalmologists one of whom, namely, Mr. J. Herbert Parsons (now Sir John Parsons, C.B.E., D.Sc., F.R.C.S., F.R.S.), was appointed Chairman of the Committee. There were also three representatives of the Cinematograph Exhibitors' Association, three representatives of the L.C.C. and three representatives of the Physiological Society.

In June, 1920, the Committee made an Interim Report which was published by the Society. This Report contained two definite recommendations relating respectively to limitation of the permissible vertical and lateral angles of view to be imposed upon viewers occupying the seats nearest to the picture screen. Since the publication of this Report (and no other was made by the Committee) local authorities in general have been guided by these recommendations in formulating their requirements as to the proximity of seats to the screen when licensing cinema premises within their areas of jurisdiction.

Although the Report of the Committee was a unanimous one the most important of its two recommendations was the subject of a reservation by the three members of the Committee representing the Cinematograph Exhibitors. In view of what follows in the present Report, we quote here the recommendation referred to as well as the reservation: they are as follows:—

Recommendation: "(1) That the angle of elevation, subtended at the eye of any person seated in the front row, by the length of the vertical line dropped from the centre of the top edge of the picture to the horizontal plane passing through the observer's eye shall not exceed 35 deg., the height of the eye above the floor-level being assumed to be 3 ft. 6 in."

Reservation: "The three representatives of the cinema industry sitting on the Committee, whilst approving Recommendation No. 1 of this report as an ideal one which will add greatly to the comfort of the public, draw attention to the absence of definite evidence of serious injury by eyestrain. In view of this fact they are of the opinion that where application of this condition to existing halls would entail serious financial hardship there is no justification for its imposition. They are further of the opinion that the normal development of the cinema theatre will rapidly remove all causes of possible discomfort."

(2) Appointment of Present Committee

In 1953 an inquiry was addressed to the Society by one local authority concerning the effects of recent developments in cinematograph displays and, in particular, whether in the light of these developments, any revision of the 1920 recommendations is necessary or desirable.

The Council of the Society accordingly decided to appoint a new Committee on Eyestrain in Cinemas (again under the chairmanship of an ophthalmologist) with terms of reference as formulated in the preceding paragraph. The constitution of the Committee included representatives of the Society, of the London County Council, of the

Cinematograph Exhibitors' Association and the British Kinematograph Society, of the Faculty of Ophthalmologists and of the Physiological Society.

(3) The Meaning of "Eyestrain"

The term "eyestrain" is a popular and not a scientific one, although a number of contributors to the ophthalmic literature of the past 60 years have used it. It is a convenient term but, like its ophthalmic equivalent "asthenopia," it is a contraction which is insufficiently descriptive and so liable to be misleading. It is really short for "strain or fatigue of the eye *muscles*."

The "eye" as popularly thought of is not subject to strain but, just as the muscles of a limb can be "strained," i.e., fatigued, by undue or unusual exertion, so can be the internal muscles which focus the eyes and, also, the muscles attached to the outside of the eyeballs for the purpose of moving these globes and holding them in particular postures.

In seeing, however, it is seldom that the small muscles inside and outside the eyeballs are the only muscles brought into action. Generally, even when we are simply occupied in watching, the muscles which move and posture the head are in use and these too may become fatigued. Indeed, the physical discomfort which may develop during prolonged viewing, whether in the cinema or otherwise, and which may provoke a complaint of "eyestrain" is often of wider origin than is implied by the term by which it is epitomised.

We have made our investigations having in mind not only "eyestrain" as meaning the strain or discomfort which appears to be felt in the region of the eyes themselves but also the discomfort occasioned by movements and posturing of the head and neck, and even of the body generally, which may be necessitated by the disposition of the cinematograph display in order to keep the display in view without unduly tiring the small eye muscles.

We would add that while "eyestrain" is most likely to occur in persons having certain uncorrected errors of refraction or latent imbalance of the external ocular muscles, it can happen to anyone if prolonged and unusual use is made of the eye muscles. It is not, however, a disease of the eyes, and it may be stated here that we are satisfied that no permanent damage to adult eyes is likely to ensue from occasional viewing under even the most uncomfortable conditions we have found during our investigations.

(4) The Work of the Committee

The Committee held five meetings and witnessed a number of film exhibitions in representative types of cinemas under different conditions as to aspect ratio of picture, curvature and tilt of screen, elevation of picture, and picture quality due to technical differences in taking the picture, preparing release prints and exhibiting the pictures. Facilities for our observations in cinemas were secured by our members representing cinematograph exhibitors, and much indispensable information, as well as plans, relating to angles of view in existing cinema premises was made available to us by the L.C.C. through their representatives. The Committee also witnessed a special film prepared by Dr. Knopp to exemplify features encountered in ordinary films which it was thought might most readily occasion visual discomfort. In addition, the Committee considered the results of an experimental investigation into the relation between picture elevation and the comfort of the viewer, made by the Group for Research in Occupational Optics of the Medical Research Council under the direction of Mr. H. C. Weston, and also the results of partly similar experiments undertaken by the Chairman.

In the early stages of our work we visited cinemas equipped with wide screens in order to judge for ourselves to what extent discomfort may arise when pictures of

different aspect ratio, up to a maximum of 2.55 : 1, are watched from various positions in the auditorium and especially from the front seats. Although the introduction of these wide screens has, in general, increased the obliquity of view of the sides of the picture, especially from the side seats nearest to the screen, so that the picture may appear seriously distorted, we came to the conclusion that the angle of elevation of the picture is more important from the standpoint of discomfort and ocular muscle fatigue than is the lateral angle of view. In this matter, therefore, we concur with the opinion expressed by the 1919 Committee. However, we found that, in order to accommodate the wide screen in some existing cinemas, it had been necessary to raise the whole screen, thus increasing the angle of elevation both of the top and the mid-point of the screen.

Although the gaze is not, of course, habitually directed to the top of the picture a high angle of elevation of the picture top generally involves a proportionately high angle of elevation to the midpoint of the picture to which attention is chiefly directed. Our experiences when watching films shown at a maximum top-edge angle of elevation of 55 deg. convinced us that the discomfort occasioned by the posture, especially of the neck, head and eyes, necessary to elevate the gaze sufficiently goes beyond that which we think should be imposed upon any viewer. Even so, in our opinion, no lasting ill-effects upon adult eyes and ocular musculature are likely to ensue from occasionally viewing pictures characterised by so high an angle of elevation. The result of the experiments to which we referred earlier, and which are summarised in the Appendix to this Report, not only confirm us in the conclusions just stated but, together with our own experiences when viewing cinema displays from different seats, have satisfied us that the recommendation made in 1920 for a maximum angle of elevation to the picture top-centre of 35 deg. is well founded.

We have no doubt that, where it exists, undue elevation of the picture in cinema theatres causes discomfort to viewers. If the requisite elevation of the gaze was attempted only by use of the extra-ocular muscles the strain experienced might be severe and in some cases would quickly become intolerable. To prevent this, the head of the viewer, and the trunk also, has to be inclined so as to assist in elevating the gaze and the total discomfort is, therefore, due to the muscular posturing of these parts as well as to that of the eyes.

The elevation of the picture is not the only feature of it which may give rise to viewer discomfort. Oculo-motor fatigue may be induced by viewing pictures in close proximity because unduly rapid excursions of the eyes are required to follow movements in the scenes depicted. Wherever the movements of the eyes fail to keep pace with the action in the picture visual confusion tends to ensue, so that coupled with the feeling of strain due to unwonted motion of the eyes there is "perceptual strain," i.e., a feeling of effort in interpreting the visual information which the viewer receives. A special film devised by Dr. Knopp was made to assist us in appraising the effects of different kinds and rates of movement such as are met with in ordinary cinematograph pictures.

Unsteadiness of the picture as a whole, abrupt changes in overall brightness, excessive brightness contrasts within the picture and poor definition are all features which, when present, excite "compensatory" actions either of the external or the internal muscles of the eyes. They, together with the manifest unusualness of the visual stimuli provided by the picture and the perceptual difficulties these may entail create that sense of stress in seeing which is often complained of as "eyestrain."

The photographic quality of cinema pictures made for projection on wide screens is now so good that they can be viewed without loss of definition due to graininess at shorter range than films made by earlier techniques but, of course, it remains true that the closer the viewer approaches to a large screen the greater is the risk of visual stress in following the action depicted.

Slight unsteadiness of the picture resulting from mechanical movement of both camera and projector is difficult to avoid even with the most modern equipment, but in our visits to various cinemas we have not experienced any seriously disturbing picture unsteadiness although we noticed this defect occasionally when viewing pictures at very close range.

In conclusion, we would say that, on the whole, recent developments in cinematograph displays have introduced no new features likely to occasion ocular ill-effects or visual discomfort. On the contrary, we think that, at all reasonable viewing distances, discomfort is less likely to be experienced in viewing modern film productions than in the case of earlier displays, although we do not extend this opinion to 3-D film displays which, however, are not in general use.

It may be helpful to the cinematograph industry if the Committee points out to the producers of wide screen films that, if the areas of action or interest are generally kept in the upper third of the picture for long periods or if the movement of objects passing laterally across the screen is too confused or too erratic, visual discomfort and fatigue of the audience is likely to occur. Excessive brightness contrasts between successive sequences of film should generally be avoided.

The wide screen techniques which have been adopted by the cinematograph industry are not yet stabilised in type and form, and if further developments are introduced to the public it may be necessary for the Committee to reconsider the position. In respect, however, of the current techniques **it is recommended that,**

(1) In order to prevent undue discomfort and fatigue of the eye muscles when viewing cinema pictures, the angle of elevation subtended at the eyes of any seated viewer by the length of the vertical line dropped from the picture top-centre to the horizontal plane passing through the viewer's eyes should not exceed 35 deg., the position of the viewer's eyes being assumed to be 42 in. above floor-level and 6 in. in front of the back-rest of the seat.

(2) Effect should be given to Recommendation 1 in all premises erected or adapted as cinemas after the date of issue of these recommendations.

(3) Effect should be given to Recommendation 1 in premises which, at the date of issue of these recommendations, are already in use as cinemas, except that where, for structural and economic reasons, it is not reasonably practicable in such premises, including those used only occasionally for cinematograph exhibitions, to avoid exceeding the maximum angle specified in Recommendation 1, an increase in the angle of elevation to the picture top-centre may be permitted up to a maximum of 45 deg. provided that the angle of elevation to the mid-point of the picture does not then exceed 30 deg.

(4) During cinematograph exhibitions organised wholly or mainly for children in any premises as defined in Recommendations 2 and 3, effect should be given to Recommendation 1, if necessary by preventing occupation of any seats from which the angle of elevation of the picture top-centre exceeds 35 deg.

The Committee has considered the recommendation made in 1920 concerning a limit to the permissible angle of view to the sides of cinema pictures. It is felt that, while the picture may be distorted when viewed at an acute lateral angle, it is probably less important for the prevention of viewer discomfort to place a limit upon this angle than upon the angle of elevation. There is, in fact, not sufficient evidence at present to justify the recommendation of a definite limit to the lateral angle of view and, accordingly, it is suggested that the 1920 recommendation on this matter be waived for the time being.

SIGNED:

	Appointed by
W. J. WELLWOOD FERGUSON (*Chairman*)	*The Illuminating Engineering Society*
H. DAVSON	*The Physiological Society*
G. E. FIELDING	*British Kinematograph Society*
E. R. JORDAN	*London County Council*
L. KNOPP	*The Illuminating Engineering Society*
L. H. SAVIN	*Faculty of Ophthalmologists*
A. F. STEEL	*London County Council*
W. S. STILES	*The Illuminating Engineering Society*
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G. F. COLE (*Secretary*)	

June, 1956.

Appendix

Studies of the Relationship Between Picture Elevation in Cinemas and the Comfort of Viewers*

These studies were made to obtain objective evidence relevant to the problem of deciding what angle of elevation of the line of sight from viewer to picture may be allowed in cinema theatres without risk of the occurrence of undue discomfort, and particularly of "eyestrain" among viewers.

(1) The Division of Labour in Elevating the Gaze

The movements of each eye in its orbit are effected by means of six muscles attached to the eyeball and the possible extent of the movement in different directions is limited by the power of the individual muscles and the constraints imposed by their unity as a group as well as by check ligaments which are among the fastenings of the eye.

It is well known that movement of the visual axis or line of sight vertically upwards from the horizontal ahead direction cannot proceed to quite the same extent as movements in other directions. The limit is, in fact, about 43 deg., whereas in the downward direction it is about 50 deg. with intermediate values for other directions. Extreme movement of the eye in any direction is always uncomfortable; it is rapidly tiring and cannot be long sustained; it is probably never attempted in ordinary seeing and, owing to the relative weakness of the muscles chiefly concerned, a given angular movement of the gaze in an upward direction is less easy to sustain than a similar movement in other directions.

It is known, however, that the angle of elevation of the top edge of the picture from the horizontal line of sight of persons in the proximate row of seats is greater than 43 deg. and is sometimes as great as 55 deg. Thus, this portion of the picture and, indeed, lower parts which are the chief centres of interest cannot be kept in view by posturing of the eyes alone. The necessary elevation of the gaze is therefore achieved by concerted action of the extra-ocular muscles and of other groups of muscles—chiefly those which move the head on its spinal pivot and those which bend the neck and thoracic region of the spine.

In so far as "eyestrain" may be occasioned by elevation of the gaze in cinemas it is clear that the "strain" is not of the eye itself but of the muscles which turn it. Whether, and to what extent, such strain is allowed to occur depends upon how much of the required elevation is actually accomplished by the muscles of the eye and how

* These studies were made by the Group for Research in Occupational Optics of the Medical Research Council, under the direction of H. C. Weston.

much is brought about by quite different muscles which, nevertheless, subserve the end in view.

The track of the eyes in elevation of the line of sight, and the body mechanics involved, has been studied in relation to sighting (Clark, Le Gros, Weddell, G., 1944, Darcus, H. D., 1948) but only for the condition of no angling of the eyes in their sockets. According to Darcus, "it is considered desirable on physiological principles that when altering the line of vision the eyes should maintain their position of rest, that is, the position in which the least strain is thrown on the small muscles which move the eyeball within the orbit."

It cannot be assumed that this physiological principle is observed when the line of vision has to be steeply inclined upwards by persons occupying the front rows of seats in cinemas. The first of the present studies therefore consisted of observations intended to ascertain to what extent the eyes may be turned up when the line of sight is elevated from the horizontal by from 35 to 55 degrees.

Ten individuals, six male and four female, were photographed in profile and in the erect seated position while they looked at an object facing them at eye level. The object of regard was then raised so that a line from it to the eye of the observer still looking straight ahead, was inclined to the horizontal by an angle of 35 deg. The observer was then instructed to look at the object and a second photograph was taken. Other photographs were then taken after the object had been raised to increase the angle of elevation successively to 40, 45, 50, and 55 degrees.

From these photographs two angles were measured, (a) the angle of inclination of a line from the eye representing the visual axis if the eye had been in the position of "rest" when the head was tilted back to look at the raised target; (b) the angle of inclination to the line defined in (a) of another line joining the eye to the elevated target. The sum of these two angles is approximately equal to the angle of elevation of the object of regard from the horizontal line of sight, and the angle defined in (b) is evidently that to which the eye is turned up in its socket.

When these measurements were averaged for the 10 subjects they showed that, when the elevation of the target was 35 deg., the required elevation of the gaze was accomplished as to 50 per cent. by superduction of the eyes and 50 per cent. by tilting the head and bending the neck. As the elevation of the target was increased up to the 55-deg. limit, the superduction of the eyes increased to a lesser extent than the increase in angling of the head and neck, so that the contribution of the eyes to the required elevation of the gaze diminished from 50 per cent. to 36 per cent. Analysis of the results by sex showed that male subjects tended to maintain the 50-50 ratio over the whole range of target elevations while the female subjects showed comparatively little change in superduction throughout the range but changed the inclination of their line of sight to a greater extent by adjustments of the head and neck. This difference of behaviour is probably due to the difference of clothing rather than to any sex difference in tolerance of superduction of the eyes: the stiffer neckwear customary with men offers greater resistance to bending of the neck than is experienced by women.

Further photographs were taken of some of the subjects when they were provided with base-up prisms before each eye. The object of these experiments was to find whether the degree of optical elevation of the line of sight given by the prisms would be used by the subjects to minimise the superduction used in looking at the elevated targets or to minimise the postural adjustment of the head and neck. It was found that advantage was always taken of the prism assistance to lower the eyes themselves towards their position of "rest" rather than to bring the head and neck nearer to the normal erect position. When looking at the target elevated to 35 deg. through prisms which inclined the line of sight by 17 deg. there was no superduction of the eyes; the required additional elevation of the gaze was achieved by head and neck posturing. Using the same prisms (of 30△) before the eyes when viewing the target elevated to 55 deg., the superduction of the eyes was only 6 deg., whereas without the prisms it was about 23 deg., i.e., rather more than half of what is anatomically possible. Such prisms are quite unsuitable for use as visual aids in the cinema owing to the serious distortion of the field which they produce.

In the foregoing experiments the visual axes had to be directed to the elevated object of regard only for the brief time required to photograph the subject, and it is doubtful whether the amount of superduction of the eyes used in fixating the target

even at its lowest angle of elevation (35 deg.) could have been sustained. Moreover, in watching an ordinary cinema exhibition the top of the picture is not usually of much interest but, although the inclination of the line of sight will be of lower degree during most of the performance, it has to be sustained for a lengthy period. Observation in cinemas has shown that viewers in positions which make a high angle of regard necessary tend to recline in their seats, thus assuming a posture of the trunk, as well as of the head and neck, which keeps down the demand for superduction of the eyes. It was, therefore, necessary to make further and more realistic experiments before conclusions could be drawn as to the risk of ocular muscle strain associated with the angle of elevation of cinema pictures.

(2) Experimental Cinematograph Performances : Effects on Viewers of Varying the Angle of Elevation of the Picture

Short feature films of 17 to 20 minutes' running time were viewed by five male and four female subjects of ages ranging from 19 to 60 years. Each subject attended five exhibitions at each of which the top edge of the picture was differently elevated above the viewer's normal horizontal line of sight. The experimental angles of elevation were, respectively, 35, 40, 45, 50 and 55 deg. For each angle of elevation of the picture top, the vertical dimension of the picture subtended an angle at the viewer's eyes approximately equal to that associated with that angle of elevation as found from measurements in actual cinemas made by the Theatres Section of the Architect's Department, London County Council.

The postural behaviour of each subject was observed continuously during the showing of each film. In addition, this behaviour was sampled by cinematography during the performance, short bursts of profile " shots " being taken at irregular intervals according to the frequency of occurrence of noteworthy changes of posture. Scaled co-ordinates were positioned in the median plane passing through the viewer so that the extent of any postural change in this plane could be measured on the photographs. The subject's posture was photographed at the commencement of each exhibition and, by including a dark-room clock in the camera field, a record was obtained of the time during the performance when each sample was taken. To avoid interference with the picture being exhibited, filming of the subjects was done by using " blacklight " as the illuminant. Since radiation of 3,650 Å causes the lens of the eye to fluoresce and, in the conditions of the experiment, might be disconcerting or uncomfortable to the viewer, each subject wore " blinkers " to prevent direct irradiation of the eyes. The " blinkers " merely consisted of unglazed spectacle frames fitted with suitably sized aluminium side pieces and they did not restrict the subject's field of view for seeing the picture exhibited. The side pieces were adjusted to be horizontal when the subject was looking straight ahead with the head erect, so that the photographs taken during the performance enabled any forward or backward inclination of the head to be measured.

The subjects were encouraged to make comments during the performances, and after viewing a film at each angle of elevation they were asked for " any complaints " without any leading questions being put to them.

Six of the nine subjects made no complaint of " eyestrain," even after viewing pictures at the greatest angle of elevation, but all subjects complained of " stiffneck " or " neckache " and some of " aching shoulders " with the three greatest angles of elevation. One viewer thought the discomfort of 45-deg. elevation might be tolerated for an ordinary cinema performance but the remainder considered that an angle of 40 deg. provoked as much discomfort as they would ordinarily tolerate. All the viewers agreed that an angle of elevation of 35 deg. was " not too bad " although a smaller angle would be preferred. Three viewers complained of ocular discomfort with angles of elevation of 45 deg. and over, and one of these mentioned that, with these angles, viewing had such a pronounced hypnotic effect that difficulty was experienced in keeping awake for the whole duration of the performance.

Inspection of the photographic records showed that elevation of the gaze to the " action area " of the picture—which is seldom located near the upper edge—was generally achieved mainly by backward tilting of the head about its spinal pivot and by slumping the trunk in the seat, posturing in this way becoming more pronounced as

the angle of elevation of the picture top was increased. Two subjects slumped to a semi-recumbent posture during exhibition of the picture at the two greatest angles. It was also apparent that most of the subjects became progressively more restive during the viewing period with successive increments of elevation. Two were extremely restless with pictures at 50 deg. and 55 deg.; they frequently changed their posture in an attempt to relieve discomfort and one was provoked to massage the nape of the neck during the performance, although others deferred this gesture until the performance was concluded. One subject rubbed the eyes after watching the film at angles of elevation of 45 deg. and over.

From these experiments it is concluded that discomfort due to action of the extra-ocular muscles in turning the eyes far upwards so soon becomes acute that, when watching cinematograph pictures of high elevation, the strain of elevating the gaze is for the most part transferred to the larger muscles of the neck and shoulders. The discomfort thus produced, although unwelcome, is preferred as the lesser of two evils. The experiments suggest that this discomfort is moderate and not unacceptable when the angle of elevation to the top of the picture is as much as 35 deg., which means that the centre of the picture will then have an elevation of about 20 deg. The occasional watching of cinema exhibitions at such an angle of elevation is unlikely to be accompanied by undue fatigue of the eye muscles themselves.

It seems clear, however, that this angle of elevation cannot be exceeded by more than 10 deg. without evoking from viewers postural responses which are undesirable and productive of undue fatigue and even pain, although, even so, the musculature of the eyes themselves may be less affected than that of other regions of the body.

(3) Choice Experiments: Determination of the Maximum Acceptable and of the Greatest Preferred Angle of Elevation of the Picture

Forty subjects—20 male and 20 female—viewed a film and were able to vary the height of the picture on the screen by turning a knob mounted on the arm of their seat. They were asked to make two settings (a) to set the picture at the height they would prefer to view it throughout a normal cinema programme and (b) to set the picture at what they regarded as the maximum acceptable height for the duration of a normal cinema performance.

The significant characteristics of the seat provided were similar to those of cinema seats. The height of the seat was such that the mean seated eye height of the subjects was 42.5 in. The rake of the back of the seat was 17.5 deg. and the seat itself was inclined upwards from back to front, the angle between its plane and the horizontal being 4 deg. Although, for convenience, the mean distance of the subjects' eyes from the screen was appreciably less than the actual distance from the front seats of cinemas to the screen, the size of the picture shown was chosen so that the vertical angular subtense of the picture was similar to that actually found in cinema practice.

The results obtained are summarised in the accompanying table. The mean value for the greatest acceptable angle of elevation of the picture top-edge is approximately 4 deg. below the angle of 35 deg. now prescribed. The consequential angle to the centre of the picture is 20 deg. The preferred values of these angles are considerably lower. When analysed by sex, the results show that women accept a somewhat higher angle than men. The difference is about 3 deg. for the greatest acceptable angle to the picture top-edge. This difference is statistically significant (at the 1 per cent. level). As to the mean preferred angles, the differences between the values chosen by men and women are smaller and do not exceed their standard errors. Even for the women, however, the mean greatest acceptable angle to the picture top is 2 deg. below the now allowable maximum. The distribution of the angles of choice was wider for the men than for the women and was narrower both for men and women for the (b) than for the (a) choice, i.e., the greatest acceptable angle appears to be the more definitely determinable of the two angles of choice. Ten subjects, 25 per cent. of the total, made settings of 35 deg. or higher, up to 40 deg., for the greatest acceptable angle to the picture top: three of these were men and the remainder women. Eight subjects wore glasses and another wore contact lenses; the mean of their choices of greatest acceptable angles was less than half a degree below the grand mean of all subjects. The greater angle to the picture top which women will tolerate as compared with men

Table of Angles of Choice

40 subjects

	Preferred angle to picture		Greatest acceptable angle to picture	
	Top	Centre	Top	Centre
Lowest setting	+ 8.0	— 6.5	+21.0	+ 9.0
Highest setting	+29.5	+17.0	+40.0	+31.5
Mean (40)	+18.7	+ 6.2	+31.3	+20.2
Standard error	± 0.87	± 0.97	± 0.68	± 0.79
Standard deviation	± 5.5	± 6.2	± 4.3	± 5.0

20 males

Lowest setting	+ 8.0	— 6.5	+21.0	+ 9.0
Highest setting	+29.5	+17.0	+40.0	+31.5
Mean (20)	+17.9	+ 5.3	+29.7	+18.2
Standard error	± 1.44	± 1.57	± 1.03	± 1.16
Standard deviation	± 6.4	± 7.1	± 4.6	± 5.2

20 females

Lowest setting	+10.0	— 3.0	+27.5	+16.5
Highest setting	+25.0	+14.0	+38.25	+28.5
Mean (20)	+19.6	+ 7.1	+33.0	+22.3
Standard error	± 0.94	± 1.1	± 0.58	± 0.76
Standard deviation	± 4.2	± 4.9	± 2.6	± 3.4

is almost certainly due to the fact that their clothing allows of more extension of the neck before any restriction is felt than does that of men: there is other evidence that it is not due to any greater tolerance of superduction of the eyes.

Although the sample studied was small, it can be estimated from the standard errors of the sample mean values that for a much larger population of similar composition, i.e., adults within the age limits 19-60 years, the true value of the mean greatest acceptable angle of elevation of the picture top is unlikely to exceed 33 deg. or to be less than 29.5deg. (merely by coincidence these limiting values correspond with those of the male and female sample means).

It is concluded from the results of these choice experiments that the angle of elevation of the top edge of the picture should not exceed 35 degrees.

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